OIL POLLUTION – THE NATURE OF THE PROBLEM

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The World Oil Situation

Industrialized society is exhibiting an ever-increasing need for refined products derived from fossil fuels. This is particularly true of North America, the world's largest oil consumer. It is estimated that by 1980, the United States and Canada will consume 7.7 billion barrels of oil per year (Nickel 1969).

However, proven reserves in North America are only in the neighbourhood of 50 billion barrels:

Texas	19	billion barrels
Louisiana	9	" "
Alberta	>9	" "
Alaska	10	" "

At present, consumption is approximately 15 billion barrels per day, and expanding at the rate of 1/2 million barrels per day each year. As a result, consumption by 1980 will have been approximately 30 billion barrels more than the above proven reserves (Nickle 1969).

World oil reserves are now set at 467 billion barrels - 80% being located in the Eastern Hemisphere:

Africa	15	billion barrels
Russia and other Communist countries	55	" "
Middle East	300	" "

At the 27 billion barrels per year world consumption rate estimated for 1980, this would only last about 17 years (Abelson 1971; Nickle 1969).

The effect of this increased demand for oil has been to spur exploration further and further afield. Petroleum is now found in all the continents and most of the continental slopes (north slope of Alaska, North Sea, off western Africa and off southern Australia) (Abelson 1971). Still, there is a need to nearly double the discovery rate of oil for North America to maintain a state of self-sufficiency (already 20% of North American needs are being satisfied by supplies from overseas). This is reflected on the Canadian scene by the number of acres under permit for oil and gas exploration

(Nickle 1969):

Alberta	400	million	acres
Yukon and N.W.T.	310	"	"
Beaufort Sea and Arctic Islands			
Labrador and Nfld Coast	200	"	"
Nova Scotia and St. Lawrence Gulf			
Hudson Bay	100	"	"
Pacific Coast	16	"	"

From the above, one can see that the possibility of accidental spills, blowouts, pipeline fractures and oil tanker incidents will increase. Larger and larger tankers will be built to facilitate economical transport of oil to world marets - latest plans are for a monster of 447,000 tons (Anon 1970).

Oil pollution due to natural seepage of crude from oil-bearing rocks has been known since Biblical times (Mitchell et al. 1970). In areas such as Coal Point, Santa Barbara, California this may amount to 50-70 barrels per day (Allen et al. 1970; Mitchell et al. 1970). It first became a recognized problem in 1954 in the Caspian Sea as the result of a shipping accident (Hawkes 1961). At present, approximately 10,000 oil-spill incidents occur each year around the world (Buchman 1970), adding from 1 to 100 million tons to the oceans each year (Blumer 1970; Pilpel 1968). Despite recommendations and regulations for oil storage in holds (load-on-top method), at least 20% of the world's tanker fleet continues to discharge 600,000 tons of oil per year during cleaning of their holds (Anon 1970).

Although a recent survey concluded that 80% of oil spills occur within 10 miles of shore (Anon 1970), oil seems to be ubiquitous on the seas. One need only recall that during Thor Heyerdahl's recent voyage across the Atlantic Ocean in the "Ra" he noted that lumps of solidified oil occurred on 1400 miles of this route (Anon 1970).

Composition of Crude Oil Spills

Since 90% of recent oil-spill incidents involve crude or residual oils (Anon 1970) and since a large number of different crude oils exist, some with widely-differing properties (including toxicity) only a general description is feasible here (Carthy and Arthur 1968). Crude oil is a collection of hundreds of different substances: compounds including such heavy metals as vanadium and nickel; compounds of sulphur, nitrogen and oxygen; however, the largest proportion is composed of hydrocarbons. The latter can be divided into three broad classes: paraffins (aliphatics), aromatics and cycloparaffins (Rossini 1960). Thus it can be seen that these compounds possess a wide range of boiling points, but the most soluble are those with a boilin point of less than about 150°C, with lower molecular weight, and carbon number less than about 10 (Carthy and Arthur 1968). These are also compounds which are the most volatile and at the same time the most toxic (particularly the aromatics such as benzene, toluene and xylene) (Anon 1970; Chant 1970; Holcomb).

Malena (1964) lists several examples of the toxicity of isolated hydrocarbons on various organisms, two of which are listed:

Chlorella pyrenoidosa

Compound	*Toxic level*
ethylbenzene	> 0.1 mg/l
phenol	>10 mg/l
xylene	> 1.0 mg/l

Gambusia affinis (mosquito fish)

Compound	*Toxic level*
benzene	386 mg/l (96 hr TL_m)
phenol	56 mg/l
toluene	1180 mg/l

Ecological Effects

A major proportion of oil pollution of the sea occurs in its most productive areas - the surface and littoral waters (Anon 1970; Hawkes 1961). In addition to the composition of the oil itself, there are many varying physical, chemical and biological factors which can influence its fate, such as: currents, light, temperature, weathering and presence or absence of a "seed stock" capable of decomposing it. In addition, a range of sensitivities may exist within members of a community (Mitchell 1970). The above-mentioned factors may account for the difference in opinion expressed by many workers as to the actual effects of oil pollution. Basically, it may affect saltwater animals in several possible ways (Hawkes 1961):

1. tainting of the flesh of fish and shellfish
2. poisoning by ingestion of oil or its soluble fractions
3. mechanical fouling
4. repellant effects
5. upsetting of food chains (Horn et al. 1970).

The last point may be the most important of all, particularly if lower members of trophic levels are deleteriously affected.

In view of the fact that community analysis as a means for assessing damage may be most helpful, a short look at three recent "case histories" is in order:

1. Tampica Maru. This tanker ran aground on 29 March, 1957 on the Pacific Coast, near the border of the United States and Mexico (Mitchell 1970). Twenty thousand barrels of her cargo of diesel fuel were spilled, and the remaining 40,000 barrels lost over the following 9 months, resulting in what might be termed *Chronic* oil pollution. Surveys conducted one month after the wreck disclosed severe mortality in marine communities one-half mile on either side of the wreck (dead invertebrates and fish, barren tidepools, and mussel beds containing many dead organisms). Sludge formed by intense wave action and sediment killed many bottom organisms to depths of fifteen feet. In addition, abnormal behaviour patterns were observed among intertidal organisms up to 5 miles from the wreck. Only 4 animal and 13 plant species remained. However, within three months, a dense growth of seaweed was observed due to the absence of grazing organisms. After a period of 3 to 4 years the biota was approximately 90% restored, having 71 animal and 58 plant species.

In contrast to the following example, it is important to note that the oil was spilled close to the shore, thus undergoing little weathering, and also that it was composed of a more refined product.

2. Torrey Canyon. The wreck of this ship in 1967 resulted in a loss of 3 million gallons of Kuwait crude oil to the sea near England and France. The massive application of detergents complicated any attempts to study the effects of the oil itself (O'Sullivan and Richardson 1967). Studies conducted on the affected British Coast (Nelson-Smith 1968) disclosed an altered balance in the littoral zone, the grazing organisms such as limpets and sessile organisms such as acorn barnacles and *Fucus* being affected (George 1961). The periwinkle *Littorina littorea* was particularly sensitive (Nelson-Smith 1968). In this case, it should be noted that the oil was quite weathered by the time it reached the shore, so that the content of volatile compounds was probably quite low.

Along the 50 km coastline of Tregor, France it has been estimated that, to a depth of 15 m, 100,000 tons of algae and 35,000 tons of fish were destroyed. The French avoided the use of detergents (Chipman and Galtsoff 1949).

3. Santa Barbara Channel. The oil spill, here, began on 28 January, 1969. During the following 6 months, 300,000 to 3,000,000 gallons of crude oil were lost due to a blowout on a drilling platform in the channel (Anon 1971; Mitchell et al.

1970). At present, most of the oil is thought to be in the basin of the channel, having been adsorbed into particles of silt and sunk. According to Dr. Saunders of the Allan Hancock Foundation, damage to the flora and fauna was much less than predicted. However, one variety of barnacle was smothered and 4,000 seabirds died (90% of which were Western Grebes) (Anon 1971). Another survey (Mitchel et al. 1970) indicated that, while communities were at first mostly normal, after one month significant mortalities occurred in upper intertidal communities - mussels, barnacles, limpets and periwinkles being mainly affected.

Summary of Possible Effects

1. a thick oil layer (if greater than 3 cm) may prevent gaseous exchange, particularly in shallow areas (Galtsoff 1936; L'Hardy 1968).
2. aesthetic pollution of beaches and the coating of sessile organisms.
3. generally, regardless of the type of oil involved, birds, particularly sea-birds, are seriously affected. The natural act of preening oily feathers results in ingestion of oil, followed by internal lesions which often result in sloughing of the gut lining. Also, the removal of natural insulation provided by an air layer between body and feathers results in loss of buoyancy, and inevitably, respiratory diseases (L'Hardy 1968).
4. change in the balance of the ecosystem, particularly if oil pollution is chronic (greater than the rate of ecosystem recovery) (Bellamy 1967; Blumer 1970; Pilpel 1970).
5. persistence of carcinogenic chemicals present in oil (such as 3, 4-Benzopyrene) in bottom muds or concentration in food chains (Chant 1970; Holcomb; Reimann 1968).
6. behaviour of sea animals may change, either due to the anaesthetic effect of aromatic soluble compounds (O'Sullivan and Richardson 1967) or due to saturated higher boiling - point compounds (Holcomb).

Treatment of Oil Spills

Many methods and materials are available for the treatment of oil spills, although none is entirely satisfactory. Mechanical methods aim primarily at a recovery of the spilled oil, which is adsorbed on straw, foam or other materials, or skimmed off the surface, or contained (prevented from spreading) by floating booms. Chemical methods aim primarily at dispersing the oil in water, in the form of an emulsion of tiny oil droplets, by means of detergent.

During the Torrey Canyon clean-up the detergents used (2,000,000 gallons) proved to be much more toxic than the oil itself (Bryan 1969; Conder 1967; Nelson-Smith 1968). It also increased the toxicity of the crude oil (Kühl and Mann 1967). This may be due to the fact that one of the detergents used BP 1002, was compose of a stabilizer, 10 to 15% of actual surfactant, and 80-90% of toxic solvent - in this case kerosene (Galtsoff 1968; Corner et al. 1968). In tests, this was shown to affect pilchard fish eggs and phytoplankton present in the upper oceanic layers. At concentrations of 10 mg/l BP 1002 killed marine invertebrates of many phyla. Most crustaceans and molluscs were wiped out, except barnacles and molluscs possessing an operculum (Bryan 1969). Larval stages were found to be more susceptible than adult stages of many organisms. Some examples from toxicity tests:

Organism	*Toxic level (mg/l)*	
	BP 1002	*Kuwait oil*
[1]Nucella lapillus	1.0 - 2.5	100 - 1000
[2]Elimius modestus	5	
[3]Sabellaria spinulosa (larvae)	1.0 - 2.5	

In general, high intertidal life forms were most sensitive (Rosenthal and Gunkel 1967; Tracy et al. 1969). In some cases algal growth (brown and green algae) flourished after treatment and disappearance of herbivorous molluscs. However, detergents were fatal to algae such as *Phaeocystis*, *Coccolithus*, *Halosphaera and Gymnodinium* and capable of killing most aerobic, oil degrading bacteria (Galtsoff 1968). Thus their application in shallow littoral areas where the dilution factor is at a minimum seems to be most dangerous.

The Fate of Oil in Nature

Unlike many of the products man liberates into the environment, crude oil is a naturally-occurring substance (e.g. many natural seepages along the California coast).

The presence of oil in the biosphere may have encouraged the evolution of microorganisms capable of utilizing carbon and other elements present in oil (Reimann 1968). This may be an important factor in preventing the accumulation of oil on the Earth's surface (Mackin and Hopkins 1961).

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[1] (Bryan 1969)

[2] (Corner 1968)

[3] (Wilson 1968; Wilson 1968)

A number of natural processes exist which operate on oil and eventually result in its disappearance (Pilpel 1968). These may be broadly classified into two groups (Pilpel 1970):

Dispersal

- evaporation of volatile components
- emulsification
- sinking due to adsorption on silt etc.
- beaching ashore

Destruction

- auto-oxidation (chemical conversion in the presence of oxygen and sunlight)
- microbial oxidation - this is from 10 to 100 times faster than auto-oxidation, particularly in the presence of nutrients, oxygen and higher temperatures (Malina 1964; Marion and Malaney 1963; Pilpel 1970). It may be carried out by a wide variety of bacteria, molds, fungi and actinomycetes (Anon 1970; Bachman 1970; Holcomb; McCauley 1966; Shaposhnikov et al. 1968; Wallhauser 1968). However, it does have a high oxygen demand, the oxidation of one liter of mineral oil requiring the oxygen content of 12,800 gallons of seawater (Chant 1970; Zobell 1962) and may involve potentially toxic intermediates (aldehydes, ketones, ethers, esters etc.). Since the eventual product of oxidation is usually CO_2, this may also have an effect on the algal growth (Ludack and Kinkead 1956).

  The increased growth of bacteria is stimulated by the presence of oil has been shown to inhibit the growth and eventually cause the death of the diatom *Nitzschia closterium*, a food source for many filter-feeding molluscs (Gatsoff 1936; Hawkes 1961; Stewart 1970).

In view of the general fact that oil spills are such a common occurrence today and that these oils are composed of so many compounds, - some with known, but many with as yet unknown effects on aquatic organisms - it certainly seems of utmost importance that more research be done on its effects. Studies begun with individual organisms must then be used as a basis for examining the whole ecosystem of a particular locality. This latter task is particularly difficult, since so many factors (bacteria, temperature, light, wave action etc.) combine to affect the fate of oil and its action on the community.

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